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Proposed New Requirements for Booster Amplifiers

Supporting Documents

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Oscillation Protection in Cell Phone

Booster Amplifiers

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1. Purpose

This report presents proposed tests and criteria for oscillation protection in cellular booster amplifiers.

2. Background

Booster amplifiers are used for improving the performance of cellular handsets used in marginal locations. Improperly designed amplifiers are capable of meeting all existing FCC requirements while still causing extensive interference to cellular systems due to their self-oscillation. Assuming that a manufacturer has considered the self-oscillation problem and that his user manual is carefully worded in an attempt to solve this problem, there is no certainty that such amplifiers will be installed as directed. Even when carefully installed according to a manufacturer's user manual, such installations will remain ineffective against end-user intervention. One commonplace occurrence oftentimes happens in a car-wash when the (magnetically mounted) outside antenna is removed from the roof and placed on the back seat of the vehicle resulting in a high power oscillation that blocks cellular (and possibly other) services. Therefore, there is a definite need to require tests and establish criteria to ensure that FCC grants are issued only for booster amplifiers that are proven to have satisfactory protection against self-oscillation.

3. Test Concept

The general concept is to connect the amplifier with a controlled amount of feedback while monitoring the amplifier for possible oscillations. This is illustrated in figure 1.
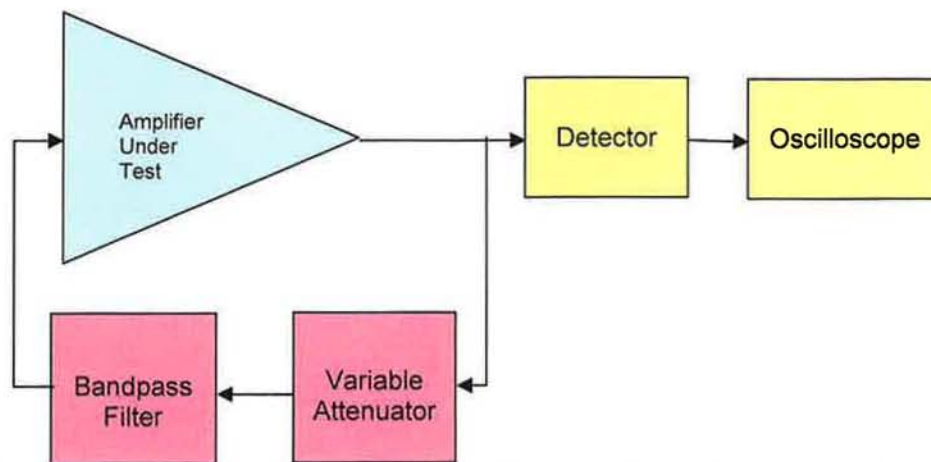

Fig. 1 - Conceptual Test Set-up

In order to ensure that an amplifier is properly protected in all of its intended bands, it is necessary to evaluate each band separately. This is because an amplifier could have protection in only one of its bands (whether by design or because of malfunction). Without separately testing each band (e.g. by doing a broadband test without bandpass filters), such an amplifier would appear to be satisfactorily protected against oscillation even though that would not be true in a real-world situation. This is because the attenuation of the feedback path can vary greatly as a function of frequency so that there is more attenuation in the protected band than in the unprotected bands. As a result, the amplifier could

oscillate in one or more of the unprotected bands without activating its single-band oscillation protection.

Signal path attenuation that varies with frequency can be caused by several factors, e.g:

1. Propagation losses including multi-path and reflective differences
2. Antenna gain
3. Transmission line loss
4. Obstructions, structures, vegetation, etc.

4. Test Procedure

4.1 Preliminary Gain Measurement

If the amplifier has adjustable gain, it should be adjusted for maximum gain. The maximum gain of the amplifier shall be measured in each of the frequency bands of intended operation. A typical dual-band amplifier would require four gain measurements (forward link and reverse link for both the 800 MHz and 1900 MHz bands). This can be done by any of the usual means, e.g. by a network analyzer, or by a signal generator and power meter, etc.

4.2 Oscillation Protection Test

a. Refer to figure 2. Connect the variable attenuator to the bandpass filter for the band being evaluated.

b. Connect the attenuation measuring equipment in place of the amplifier, and by using the variable attenuator, set the loop attenuation to be 15 dB greater than the measured amplifier gain in the band being evaluated (see 4.1).
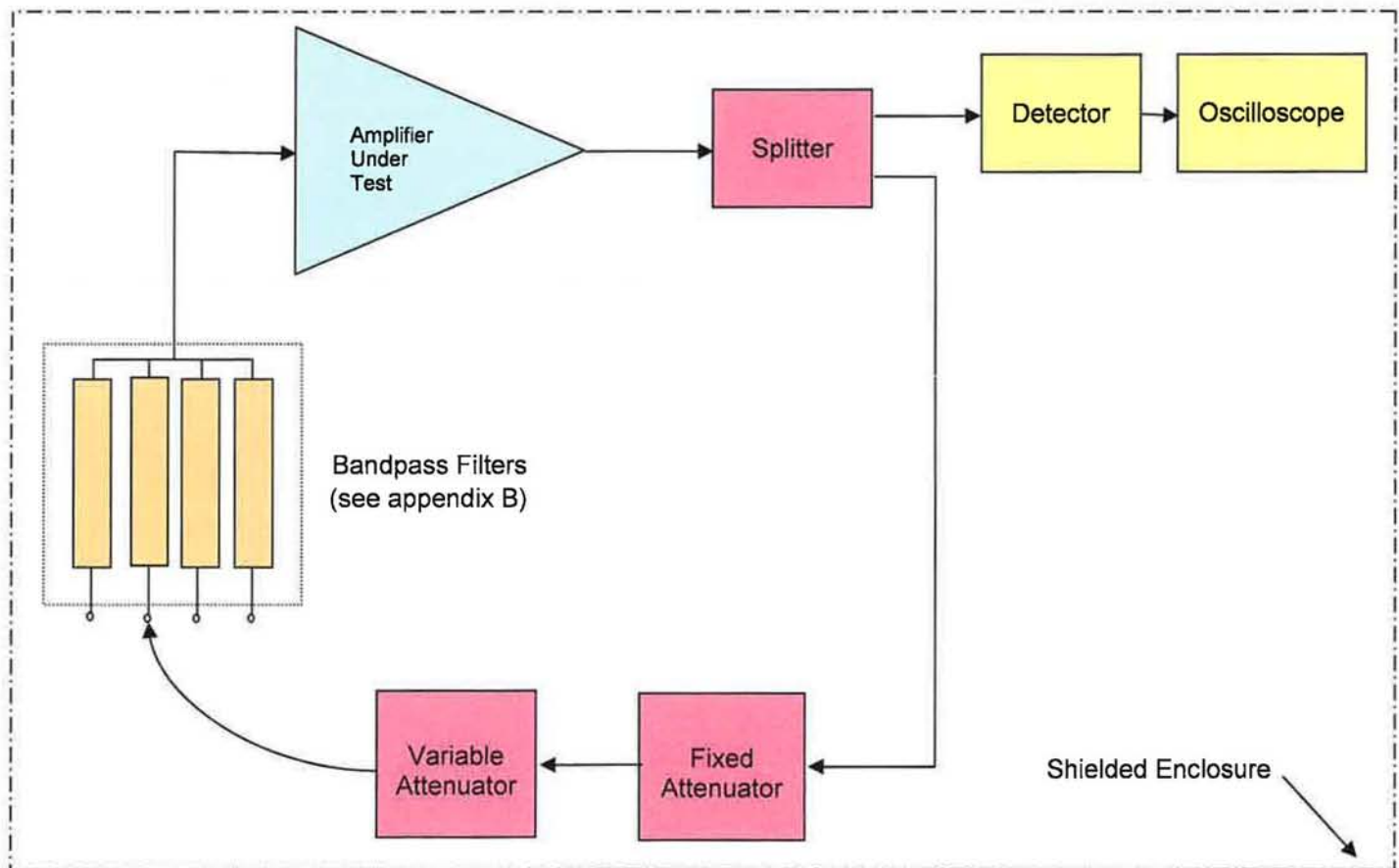

Fig. 2 - Oscillation Protection Test Setup

c. With the amplifier switched off, connect it in place of the attenuation measuring equipment. Make sure that the amplifier's "high" output is connected to the splitter. The connection to the splitter will change depending upon whether a forward link band or a reverse link band is being evaluated.

d. Turn on the amplifier. With the oscilloscope's storage mode and trigger both turned off, set oscilloscope gain to give approximately 2 cm deflection due to residual noise. Set the sweep speed of the oscilloscope to approximately 100 milliseconds/centimeter. Next, set the oscilloscope trigger to be as sensitive as possible without being triggered by the amplifier's residual noise.

e. Reduce the attenuation in steps of 1 dB or less until the there is no attenuation. This may require using different valued fixed attenuators, and finally, the fixed attenuator must be removed altogether. At the same time, carefully monitor the oscilloscope for any signs of oscillation which would be evident by changes in vertical deflection.

f. If oscillation is noted, it shall be further evaluated by determining if it is a sustained oscillation, or a momentary (transient) oscillation. If it is a momentary oscillation, then the length of time that the oscillation exists shall be measured with the oscilloscope using storage mode as necessary.

g. Repeat "a" through "f" for each of the amplifier's intended frequency ranges.

h. Repeat "g" five times.

5. Pass/Fail Criteria

5.1 Any sustained oscillations are a failure.

5.2 Momentary oscillations are permitted provided that the amplifier includes hardware and/or software for reducing gain (or shutting off) so that any such momentary oscillations are acceptable to the operators of the cellular system(s) in which the amplifier operates.

Appendix A – Equipment List

The specific test equipment used in the tests is the prerogative of the test laboratory performing the tests provided that the equipment meets the requirements of this section. The test report shall list the manufacturers and model numbers of the equipment that was used.

1. **Oscilloscope, detector and splitter.** Must be capable of detecting a 0 dBm signal into the splitter (see fig. 2). This shall be from frequencies that are 100 MHz below the amplifier's lowest intended frequency to frequencies that are 100 MHz above the amplifier's highest intended frequency. The oscilloscope shall be capable of storing an image in order to facilitate the evaluation of transient events. The splitter's insertion loss shall not exceed 5 dB in the feedback path (i.e. between the splitter and the fixed attenuator in fig. 2).

2. **Power Supply.** Suitable for the amplifier being tested.

3. **Variable Attenuator.** Precision attenuator with at least 1 dB resolution and ±1 dB accuracy from frequencies that are 100 MHz below the amplifier's lowest intended frequency to frequencies that are 100 MHz above the amplifier's highest intended frequency.

4. Attenuation measuring equipment. Capable of measurement within 3 dB accuracy. This could be a network analyzer, or alternatively a signal generator and power meter, etc.

5. Fixed Attenuator. Attenuation, as needed, to protect the variable attenuator and to enable adjusting the overall attenuation as required (by the Oscillation Protection Test, 4.2-b & 4.2-e). The accuracy of the precision attenuator shall be ±1 dB.

6. Bandpass filter. Stopband attenuation (relative to passband attenuation) at frequencies NOT being evaluated shall be given by "A" in dB, where:

$$A \geq 20 + \Delta G$$

When the maximum amplifier gain in the frequency band being evaluated is greater than the gain at any other frequency, ΔG equals zero. When the maximum amplifier gain outside of the band being evaluated is greater than the maximum gain in the band being evaluated, ΔG equals the difference between these gains (always being a positive number). Insertion loss shall not exceed 5 dB.

See Appendix B for details of a practical bandpass filter.

7. Shielded Enclosure. Tests shall be performed inside a shielded enclosure to ensure that no interference is caused to cellular (or other) services.

Appendix B – Bandpass Filter

Figure 3 illustrates a practical bandpass filter for separating the four frequency bands commonly used in booster amplifiers. It is easily fabricated with standard strip-line techniques by using commonly available diplexers and duplexers.
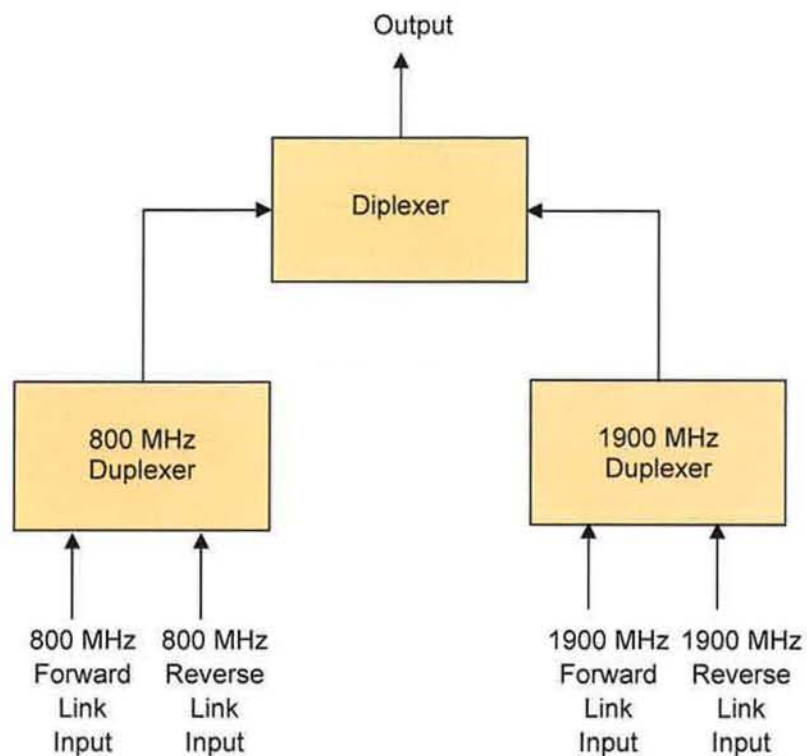
Output

Diplexer

| 800 MHz Duplexer | 1900 MHz Duplexer |

800 MHz Forward Link Input   800 MHz Reverse Link Input

1900 MHz Forward Link Input   1900 MHz Reverse Link Input

Fig. 3 - Example of Practical Bandpass Filter

Adjacent Channel Noise Protection

See page 1 of the attached document

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Base Station Overload Protection

See page 4 of the attached document

Wilson's Comments on Verizon's Technical Issues

March 8, 2010

Verizon's Statement

Wilson disagrees with Verizon's statement that "Even Properly Functioning Boosters Can Cause Interference to Wireless Networks." [1]

Verizon States Three Issues

- Adjacent channel noise increase due to higher available power than a cell phone alone.

- Broadband noise transmitted by the booster.

- Base station overload due to not meeting minimum transmitted power requirements.

Wilson's model 801201 Dual Band Wireless Booster (currently used by Telus and Bell in Canada) demonstrates the capability of producing boosters that protect base stations from all of Verizon's stated concerns.

Adjacent Channel Noise Increase

The "Near-Far" problem as explained by Verizon[2] is where "… a subscriber is "far" from the base station providing wireless service, but simultaneously "near" a base station of a different wireless service provider using an adjacent frequency block. Being far from the serving base station, the subscriber uses maximum transmit power to be heard by the network, thereby potentially causing adjacent-channel interference to the other service provider's base station. If the "far" subscriber is using a mobile booster (and this is exactly the situation a mobile booster is marketed to remedy), even higher transmitter power

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is available, worsening the adjacent channel interference problem..." **Wilson** solves this problem by employing reverse link power control using forward link sensing that ensures that the maximum output power is no different than a cell phone transmitting maximum permissible power. The booster's maximum power output is in accordance with the industry standard for cell phones[3] that allows a maximum of 30 dBm and meets Verizon's requirements.[4] Due to battery and SAR considerations, typical CDMA phones have lower maximum output powers of 23 to 25 dBm so that using a booster increases a cell phone's power by 5 to 7 dB. When a cell phone is placed in a cradle, or on a vehicle's center console, measurements have shown approximately 15 dB attenuation relative to a cell phone alone outside the vehicle. A booster's outside antenna overcomes this attenuation, thereby eliminating this 15 dB loss. Therefore, using a booster achieves a 20 to 25 dB increase in effective radiated power relative to a cell phone alone inside a vehicle. This is equivalent to a cell phone that is transmitting maximum permissible power while located outside a vehicle. This benefit is achieved without violating industry standards that are imposed upon a cell phone by itself and is compatible with Verizon's requirements (mentioned above). The booster will not extend the service area of a cell site nor violate CDMA requirements which are the most stringent in the industry.

Broadband Noise

According to Verizon[5], "... an additional problem is also present – the generation of broadband noise by the booster." Broadband noise masks weak signals thereby reducing the coverage area of base stations. It is not possible to completely eliminate broadband noise; however with careful booster design, it is possible to minimize it. Indeed, specifications received from Verizon[6] allow boosters to transmit a defined amount of broadband noise.

Wilson agrees that based upon Verizon's assumptions, the noise generated by the booster in Verizon's example would be correct, but Verizon fails to take into account Wilson's reverse link noise protection

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based upon forward link sensing. Verizon has stated[7] that 15 amplifiers, at a distance of one mile or more, shall cause no more than a 1dB increase in the base station noise floor. Based on this criterion, a single booster may cause no more than a 0.06 db increase of the noise floor.

As given by Verizon:

$$N_{out} = FGkTB$$

Expressing the above formula in dB, assuming a 290 degree Kelvin temperature, and a 1.25 MHz bandwidth (i.e. that of a CDMA channel):

$$N_{out\ dBm} = F_{dB} + G_{db} - 174_{dBm/Hz} + 61_{dB-Hz} = F_{dB} + G_{db} - 113_{dBm}$$

It follows that the thermal noise input to the base station receiver is -113 dBm
(i.e. with $F_{dB} = G_{dB} = 0$).

Verizon states that a typical base station noise floor is -111 dBm.

This implies a 2 dB increase in noise floor (relative to thermal noise) due to a base station receiver's front end noise figure (F_{dB}) and gain (G_{dB}), i.e:

$$(F+G) = -111\ dBm - (-113\ dBm) = 2\ dB$$

This is the increase in noise floor relative to thermal noise and due to a base station receiver's front end. Wilson calculations are based upon this front end noise figure and gain for base station receivers.

The Wilson 801201 booster employs noise protection based on forward link sensing which protects base stations from noise floor increases exceeding 0.06 dB. The maximum received signal, based upon a free-space path loss corresponding to 0.13 miles would be -131.6 dBm at the input to the base station's receiver terminals (assuming 15 dBi net antenna gain[8] including cable losses, etc.). Base station Forward Link power detected by the booster, together with reasonable assumptions about base station parameters that include an EIRP of 48.7 dBm[9], determines the path loss to/from the base station. Having determined the path loss, the booster is able to adjust its gain to prevent Noise Floor Interference to the base station.

The Wilson booster will shut off with a -28.9 dBm forward link received signal which corresponds to a distance of 0.13 miles. Using Verizon's "more realistic figure" [10] of 10 dB for the amplifier noise figure would require the booster to shut off for forward link signals of -34.9 dBm (or more) corresponding to a distance of 0.26 miles from the base station.

Base Station Overload

Wilson agrees that boosters without proper gain control can cause interference to base station receivers if the cell phones' power control loops cannot sufficiently reduce the reverse link power output of the booster. The Wilson 801201 Mobile Booster employs base station overload protection based upon forward link sensing. The booster's maximum gain is determined by the Forward Link signal from the "near" base station. This maximum gain point is set where the phone's power out is at the minimum of its dynamic range (i.e. -50 dBm). From this point, gain (in dB) will be reduced inversely proportional to the Forward Link signal thereby preserving the minimum power requirement (-50 dBm) of the cellular network.

Properly Functioning Boosters do not Interfere with Wireless Networks

Wilson has addressed all of the technical issues raised by Verizon, and has shown how each of these potential problems are solved by the Wilson booster. In the design of boosters, Wilson gives the highest priority to maintaining the integrity of base stations that could possibly be affected. The benefit to a subscriber is important, but causing no harm to cellular systems is even more important. As a result of this policy, there are situations wherein a Wilson booster could give little or no advantage to a subscriber. Fortunately, such situations are uncommon so that a properly functioning booster can be a beneficial part of the wireless environment without harming cellular systems, and almost always giving significant benefits.

1. *Comments of Verizon Wireless,* WT Docket No. 10-4, DA 10-14, February 4, 2010, p.15, para. 2.

2. *Id.,* p.15, para. 2, subpara. a.

3. *Recommended Minimum Performance Standards for cdma2000 Spread Spectrum Mobile Stations – Addendum, TIA-98-F-1,* Telecommunications Industry Association, June 2006, Table 4.4.5.3-1.

4. *Verizon Wireless MPE25k (Multi-Partitioned Enterprise Area of Less Than 25k sq. ft.) Over-The-Air Repeater Specifications, Requirements, and Test Procedures,* Version 1.2, May 2006, para. 2.8.

5. *Comments of Verizon Wireless,* WT Docket No. 10-4, DA 10-14, February 4, 2010, pp.15-16, para.2, subpara. a.

6. *Verizon Wireless MPE25k (Multi-Partitioned Enterprise Area of Less Than 25k sq. ft.) Over-The-Air Repeater Specifications, Requirements, and Test Procedures,* Version 1.2, May 2006, par. 2.11.

7. Id.

8. Macario, R.C.V. *Cellular Radio Principles and Design,* Second Edition, McMillan Press Ltd: Houndmills, Basingstoke, Hampshire RG21 2XS and London. 1997, p. 81, para. 3.6.1. This reference gives 17 dB as the receive antenna gain for "many" base stations. The 15 dBi figure considers a 2 dB reduction to account for losses in cables and connectors, etc.

9. Information received from Telus, Canada.

10. *Comments of Verizon Wireless,* WT Docket No. 10-4, DA 10-14, February 4, 2010, p.16, footnote 42.

Noise Floor Protection in Cell Phone Booster Amplifiers

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May 5, 2010

Noise Floor.doc

1. Purpose

This report proposes tests and performance requirements for cellular booster amplifiers in order to ensure that they will not cause an objectionable increase in the noise floor of nearby cell site receivers.

2. Background

A typical booster amplifier with a 5 dB noise figure, 60 dB gain, and a high gain antenna transmits noise power of approximately -20dBm over its passband. In a typical interference situation, a subscriber using an amplifier needs to communicate with a distant cell site of Carrier A, but the subscriber is within one or two thousand feet of Carrier B's cell site and causes significant noise increase to Carrier B's cell site receiver. An interference incident occurred in Bakersfield, California where a Wilson amplifier was causing interference to a Verizon cell site located approximately 200 meters from the amplifier's outside antenna. Together with the local engineering personnel, Wilson determined that the interference was caused by the amplified thermal noise from the amplifier. Wilson determined that adjusting the amplifier's forward link detector to shut off the amplifier whenever a forward link signal of -45 dBm (or more) was received from the cell site prevented this interference from interrupting the cell site's operation. Further tests showed that using a directional Yagi antenna on the amplifier and pointing it to reduce the forward link signal at the amplifier to be below -45 dBm returned the amplifier to operational status, amplifying the desired carrier's signal, but no longer causing interference to the base station. The use of forward link detection that shuts off a booster amplifier for signals equal to or exceeding -45 dBm (for a 60 dB amplifier) appears to be a good starting point for reducing interference caused by these amplifiers. Wilson has been investigating this problem for some time and is currently setting high gain amplifiers to shut off whenever receiving a signal that is -45 dBm or stronger. The test described in this report is a more thorough proposal that should enable setting the standard for reverse path gain reduction in booster amplifiers.

2. Test Concept

A properly functioning amplifier will reduce its gain, or even shut off, whenever it could potentially cause a cell site's noise floor to rise above a predetermined amount. The test described in this report evaluates an amplifier's transmitted noise characteristics and determines if those characteristics are acceptable or not.

The signal strength of a cell site is an indication of its proximity. It's a practical parameter that an amplifier can use to determine whether or not it's necessary to reduce its gain. When gain reduction is required, an acceptable amplifier may either shut off completely or reduce its gain to a level where the transmitted noise power will not cause an unacceptable increase in a cell site's noise floor.

The relationship between cell site noise floor increase and allowable transmitted amplifier noise power is derived. It is shown that two types of parameters are involved:

- Amplifier characteristics, i.e., Transmitted Noise Power
- Cell site characteristics, i.e., Allowable Noise increase, Radiated Power, and Receive Antenna Gain.

Cell site characteristics may be chosen that conservatively represent all cell sites thereby enabling the derivation of a simple mathematical formula that gives maximum allowable noise power output as a function of received signal strength from a nearby cell site. The Noise Floor Test presented in this report is an embodiment of this concept.

3. Noise Floor Test

4.1 Test Setup

The received cell site signal is emulated by injecting a signal generator's signal into the outside antenna port of the amplifier while the corresponding noise power output of the amplifier is measured by a spectrum analyzer. A duplexer enables separating these two signal paths. The amplifier's inside antenna port is terminated by a dummy load. This is shown in figure 1.

Figure 1
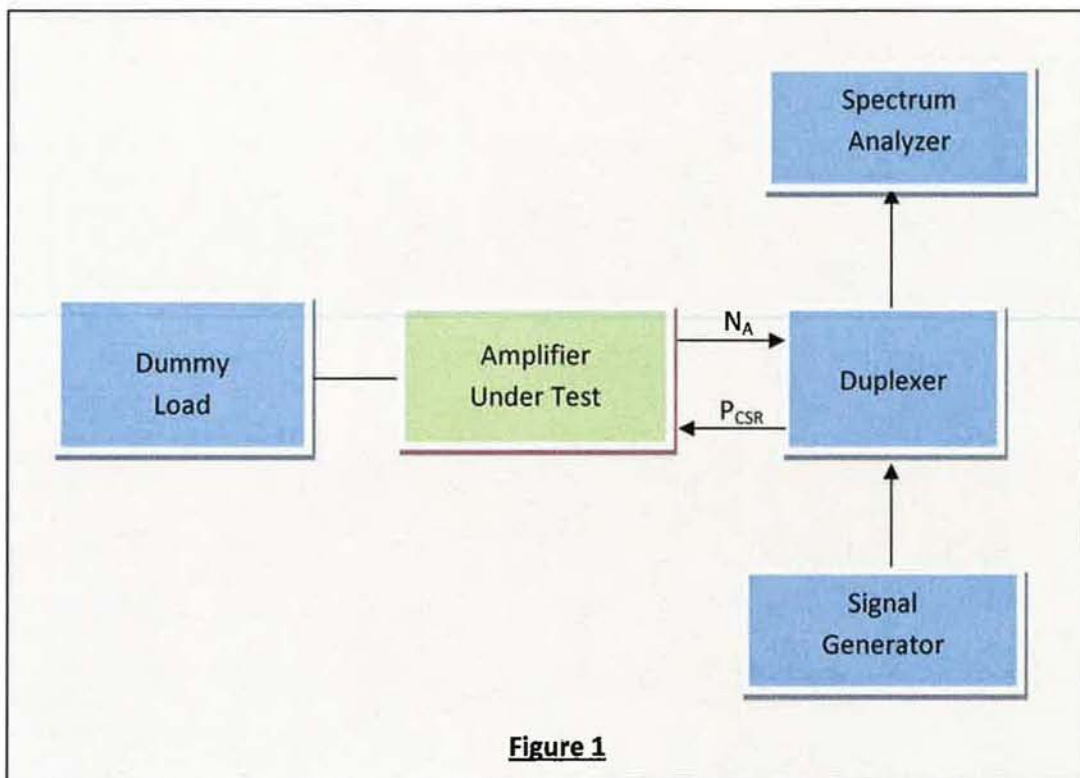
4.2 Test Procedure

Each of the amplifier's frequency bands must be evaluated separately.

4.2.1 Set the frequency of the signal generator to the forward link midband frequency of the band being evaluated.

4.2.2   Set the spectrum analyzer to sweep the amplifier's reverse link frequency band.

4.2.2   Set the output power of the signal generator:

$$Output\ Power_{dBm} = (Amplifier\ Gain_{dB} - 110_{dBm})_{dBm}$$

4.2.3   Adjust the bandwidth of the spectrum analyzer to 30KHz.

4.2.4   Beginning at the lowest possible signal generator level that enables a barely detectable reverse link noise increase when the amplifier is switched on, increase the power output of the signal generator in uniform steps of 5 dB or less, with at least 5 such steps, up to the largest possible value that would not damage the amplifier. For each step, measure and record the maximum power level of the resulting reverse link noise floor on the spectrum analyzer's screen and the corresponding signal generator output power.

4.2.5   The values for amplifier reverse link noise power and emulated base station forward link power (from 4.2.4), must be corrected to account for losses in the test setup. Determine the insertion loss of the duplexer and connecting cables. Subtract these losses from the signal generator and spectrum analyzer levels that were measured in 4.2.4 giving the forward link input to the amplifier (P_{CSR}) and the maximum reverse link noise output of the amplifier (N_A). Record these values for P_{CSR} and N_A.

4.2.6   If the amplifier has any user adjustable controls, e.g. gain controls, 4.2.4 and 4.2.5 shall be repeated for at least 5 settings chosen to uniformly span the adjustment range including both the minimum and maximum settings for each user adjustable control.

4.3 Pass/Fail Criteria

An amplifier's noise output (N_A) shall be no greater than the maximum allowable according to equation (XIV) on page ~~12~~ 10

$$N_{A_{dBm}} = M_{dBm} - P_{csr_{dBm}} + N_{T_{dBm}}$$

With $N_{T_{dBm}}$ according to equation (XV) on page ~~12~~ 10 for a 30 KHz bandwidth:

$$N_{TdBm} = -174_{\ dBm/Hz} + 10\ Log(30000) = -129.2\ dBm$$

The parameters in the above formulas are defined in paragraphs 5.2 and 5.3. An Excel spread sheet based upon these formulas greatly simplifies the evaluation of an amplifier and generates the chart in figure 2. For the purpose of illustration, the chart gives the maximum allowable noise output of an amplifier when tested with measurement bandwidth of 30KHz assuming a cell site radiated power of 48 dBm EIRP (in the direction of the amplifier), a cell site allowable noise floor increase of 0.065 dB, and a cell site receiving antenna with 15 dBi gain.

The measurement bandwidth used during testing may be changed. It is perceived that the cell site parameters would be defined as constants in a future standard that would adopt the methods presented in this report. An electronic copy of the Excel spread sheet is available from Wilson Electronics.

Amplifier Noise power vs. Foward Link Signal

Cell Site EIRP = 48dBm, Cell Reverse Link Antenna Gain = 15dBi, ΔN =.065dB

FIG 2

Allowable Working Area

Amplifier Noise power dBm @30KHZ Bandwidth

Forward Link Signal dBm
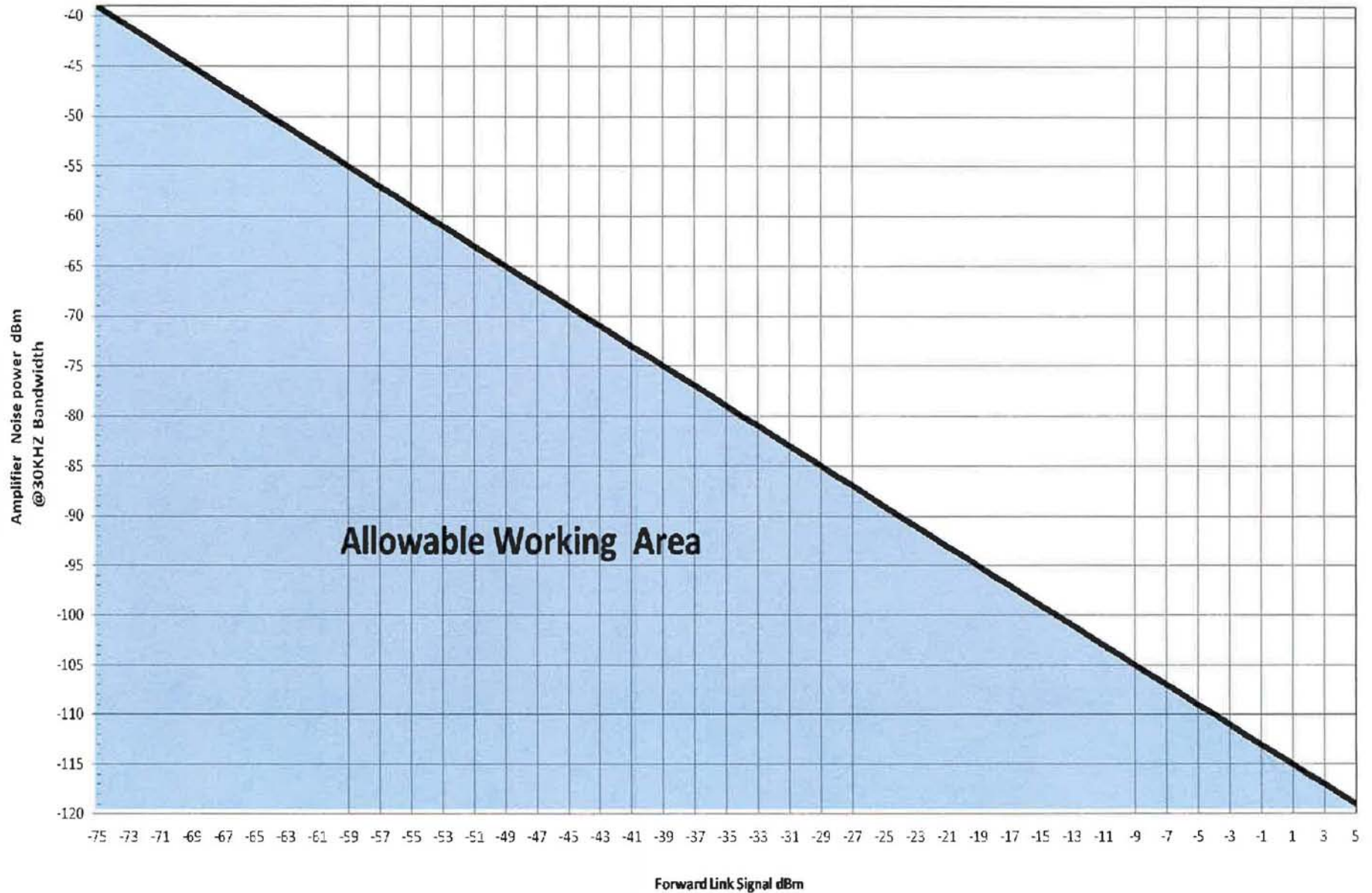
5. Mathematical Basis for Proposed Test

5.1 General Concept

A properly functioning amplifier senses and responds to a cell site's forward link signal by reducing its transmitted reverse link power whenever the amplifier could cause an objectionable increase in the cell site's noise floor. The following mathematical derivation determines the maximum allowable amplifier noise power (N_A) corresponding to the signal power received from a cell site (P_{CSR}) such that the noise floor increase at the cell site (ΔN) does not exceed an established limit.

5.2 Definitions

Note: Subscripts dB, dBi, dBm, Hz, and dBm/Hz are used to ensure correctness throughout the derivation.

$A_{A_{dBi}}$ = Amplifiers forward link Antenna Gain.

$A_{R_{dBi}}$ = Cell Site's receiving Antenna Gain.

B_{Hz} = Bandwidth in Hertz of the spectrum analyzer used in testing the amplifier.

$EIRP_{dBm}$ = Equivalent Isotropic Radiated Power of the Cell Site in the direction of the amplifier.

$F_{A_{dB}}$ = Noise Figure of the amplifier.

$G_{A_{dB}}$ = Amplifier gain.

$L_{P_{dB}}$ = Path Loss between the amplifier's Antenna and the Cell Site's Antenna.

$N_{A_{dBm}}, N_{A_{\frac{dBm}{Hz}}}$ = Noise power output of the amplifier.

$N_{T_{dBm}}, N_{T_{\frac{dBm}{Hz}}}$ = Unamplified thermal noise power.

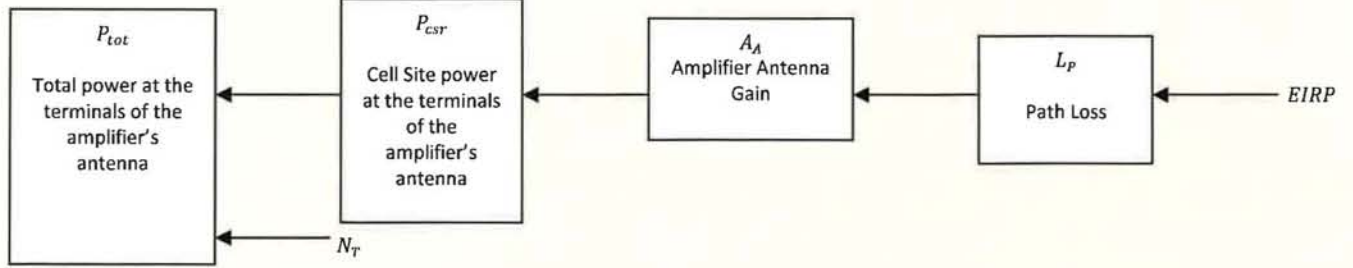$N_{wa_{dBm}}$ = Noise output at the terminals of the Cell Site receiving antenna when the amplifier is on.

ΔN_{dB} = The increase of the thermal noise at the Cell Site's receiving antenna due to the presence of the amplifier in dB relative to $N_{T_{dBm}}$.

ΔN_{dBm} = The dBm increase of the thermal noise power at the terminals of the Cell Site's receiving antenna due to the presence of the amplifier.

$P_{csr_{dBm}}$ = Cell Site power received by the amplifier.

$P_{tot_{dBm}}$ = Total power at the terminals of the amplifier's antenna.
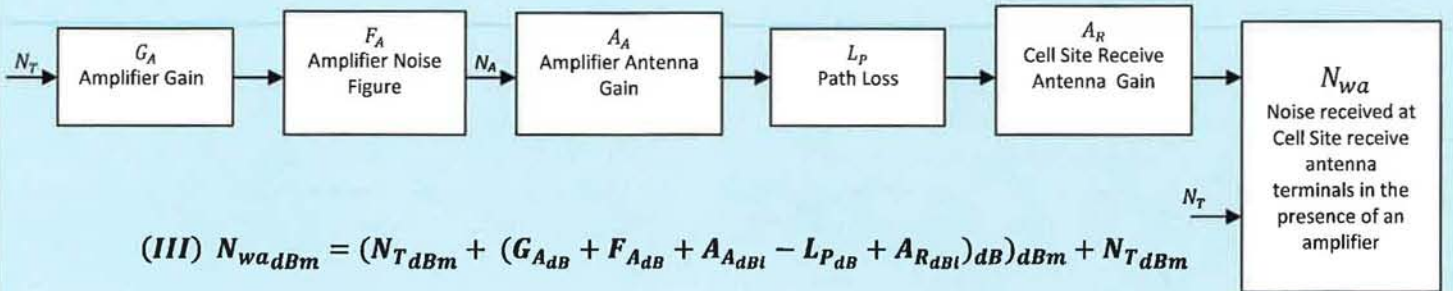
5.3 Derivation

$(I)\ P_{tot\ dBm} = P_{csr\ dBm} + N_{T\ dBm}$

$(II)\ P_{csr\ dBm} = (EIRP_{dBm} - L_{P_{dB}} + A_{A_{dBi}})_{dBm}$

$P_{tot\ dBm} = P_{csr\ dBm} + N_{T\ dBm}$ Where $P_{csr\ dBm} \gg N_{T\ dBm}$ $\therefore$ $P_{tot\ dBm} \approx P_{csr\ dBm}$

Figure 4

$(III)\ N_{wa\,dBm} = (N_{T\,dBm} + (G_{A_{dB}} + F_{A_{dB}} + A_{A_{dBi}} - L_{P_{dB}} + A_{R_{dBi}})dB)dBm + N_{T\,dBm}$

And therefore, the increase in thermal noise at the terminals of the Cell Site's receiving antenna due to the presence of the amplifier is given by:

$(IV)\ \Delta N_{dBm} = (N_{T\,dBm} + (G_{A_{dB}} + F_{A_{dB}} + A_{A_{dBi}} - L_{P_{dB}} + A_{R_{dBi}})dB)dBm$

Figure 5

Solving equation IV for L_P:

$(VI)\ L_{P\,dB} = (N_{T\,dBm} - \Delta N_{dBm})dB + (G_{A_{dB}} + F_{A_{dB}} + A_{A_{dBi}} + A_{R_{dBi}})dB$

Substituting equation VI into II and simplifying:

$(VII)\ P_{csr\ dBm} = EIRP_{dBm} - (N_{T\,dBm} - \Delta N_{dBm})dB - G_{A_{dB}} - F_{A_{dB}} - A_{R_{dBi}}$

Converting ΔN_{dBm} to ΔN_{dB} :

$$\Delta N_{dB} = (\Delta N_{dBm})_{dB} = (10 Log \frac{10^{\frac{\Delta N_{dBm}}{10}} + 10^{\frac{N_{TdBm}}{10}}}{10^{\frac{N_{TdBm}}{10}}})_{dB} = (10 Log (10^{\frac{-(N_{TdBm} - \Delta N_{dBm})dB}{10}} + 1)_{dB}$$

$$(VIII) \quad \Delta N_{dB} = 10 Log (10^{\frac{-(N_{TdBm} - \Delta N_{dBm})}{10}} + 1)$$

Proceeding from (VIII) to solve for $(N_{TdBm} - \Delta N_{dBm})_{dB}$:

$$\frac{\Delta N_{dB}}{10} = Log 10^{\frac{-(N_{TdBm} - \Delta N_{dBm})}{10}} + 1$$

Taking the Antilog of both sides and then subtracting 1 from both sides:

$$10^{(\frac{\Delta N_{dB}}{10})} - 1 = 10^{\frac{-(N_{TdBm} - \Delta N_{dBm})}{10}}$$

Taking the Log of both sides:

$$Log(10^{(\frac{\Delta N_{dB}}{10})} - 1) = Log\ 10^{\frac{-(N_{TdBm} - \Delta N_{dBm})}{10}}$$

Then simplifying:

$$Log(10^{(\frac{\Delta N_{dB}}{10})} - 1) = \frac{-(N_{TdBm} - \Delta N_{dBm})}{10} Log\ 10$$

Multiplying both sides by 10:

$$10 Log(10^{(\frac{\Delta N_{dB}}{10})} - 1) = -(N_{TdBm} - \Delta N_{dBm}) Log\ 10$$

Simplifying and rearranging :

$$(IX) \quad -(N_{TdBm} - \Delta N_{dBm}) = 10 Log(10^{(\frac{\Delta N_{dB}}{10})} - 1)$$

Substitute equation IX into equation VII to express the $P_{csr\ dBm}$ relative to ΔN_{dB}:

$$(X) \quad P_{csr\ dBm} = EIRP_{dBm} + 10 Log(10^{(\frac{\Delta N_{dB}}{10})} - 1) - G_{A_{dB}} - F_{A_{dB}} - A_{R_{dBi}}$$

From Figure 5:

$$N_{A_{dBm}} = N_{T_{dBm}} + G_{A_{dB}} + F_{A_{dB}}$$

Rearranging:

$$(XI) \quad -G_{A_{dB}} - F_{A_{dB}} = N_{T_{dBm}} - N_{A_{dBm}}$$

Substituting *(XI)* into *(X)*:

$$(XII)\ P_{csr_{dBm}} = EIRP_{dBm} + 10Log\left(10^{\left(\frac{\Delta N_{dB}}{10}\right)} - 1\right) + N_{T_{dBm}} - N_{A_{dBm}} - A_{R_{dBi}}$$

Equation *(XII)* can be written as:

$$(XIII)\ P_{csr_{dBm}} = M_{dBm} + N_{T_{dBm}} - N_{A_{dBm}}$$

Where: $M_{dBm} = EIRP_{dBm} + 10Log(10^{\left(\frac{\Delta N_{dB}}{10}\right)} - 1) - A_{R_{dBi}}$

Rearranging *(XIII)*:

$$(XIV)\ N_{A_{dBm}} = M_{dBm} - P_{csr_{dBm}} + N_{T_{dBm}}$$

Where $N_{A_{dBm}}$ is the maximum permissible noise power from an amplifier as a function of the received power from a cell site (P_{csr}), for an allowable cell site noise floor increase (ΔN), with a given radiated Power (*EIRP*) and cell site receive antenna gain (A_R). $N_{T_{dBm}}$ is a function of bandwidth and is explained in paragraph 6. Figure 2 is a plot of equation *(XIV)* for the values mentioned in paragraph 4.3.

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6. Thermal Noise Bandwidth

In order to apply equation *(XIV)*, it's necessary to determine the unamplified thermal noise (N_{TdBm}). The available thermal noise power *(N_T)* is proportional to the noise bandwidth and temperature of the amplifier being tested and is given by:

N_T=kTB   (see footnote)

Where: Boltzmann's constant, k=1.38 X 10^{-23} Joules per degree Kelvin

T= Temperature in degrees Kelvin

B= Noise bandwidth in Hertz

Assuming the Temperature is 290 K, taking the log of both sides, multiplying by 10 and converting to dBm:

(XV) N_{TdBm} = -174 $_{dBm/Hz}$ + 10 Log(B_{Hz})

The formula N_T=kTB Appears in many texts. For example, see:
Landee, Davis, and Albrecht. Electronic Designers' Handbook (New York: McGraw-Hill, 1957)
Pages 7-4 – 7-8.

Gain Balance in Cell Phone Booster

Amplifiers

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1. Purpose

This report examines the subject of gain balance in Cell Phone Booster Amplifiers and makes recommendations for required performance that should be met by these amplifiers.

2. Background

Signal-boosting cellular amplifiers are in common use by both network operators and their customers for boosting signals wherever their level is unsatisfactory. In order to function properly, a booster amplifier must have approximately the same gain in the reverse link (cell phone to base station direction) and in the forward link (base station to cell phone direction). Reasonably balanced bi-directional amplification is essential for preserving the correct relative power balance between the reverse link and forward link in the network. This balance is essential for proper operation of Open Loop Power Control, which in turn is a critical element in all CDMA systems as well as most non-CDMA systems.

Reasons for excessively unbalanced amplification include:

a. Showing "more bars" which deceives the end-user into believing that the amplifier is improving communications. If the imbalance is great enough, this will actually worsen communications when signal conditions are marginal.

b. The desire of some manufacturers to save costs by completely eliminating amplification in one direction, i.e., instead of a bi-directional amplifier, amplifiers are sold that purposely amplify in only one direction thus saving many expensive RF components. An amplifier that only amplifies in the forward link direction is being sold under FCC ID: U4O8811960A.

c. Poor engineering that doesn't sufficiently consider the importance of gain balance.

d. Insufficiently controlled manufacturing variability.

An amplifier with excessive gain imbalance disturbs the balance of the network and prevents a phone's Open Loop Power Control from functioning correctly. This could prevent the phone from establishing a call. If a call is established, the correct operation of the Closed – Loop Power Control is disturbed and may result in dropped calls. The fact that amplification is much greater in one direction

makes it unlikely that a booster amplifier can fulfill its intended function of enabling communications in areas of poor base station coverage.

This report explores in some detail how gain imbalance affects the operation of cell phones. A technical discussion is presented that shows the problems introduced by a forward link-only amplifier.

Bi-Directional Cellular Amplifier

Cellular telephone and data communications systems are inherently two-way, that is, there is a forward link (also called downlink) sending signals from the base station to the mobile, and a reverse link (also called uplink) sending signals from the mobile to the base station. This allows a conversation or interactive data session to take place.

When a booster is used to increase signal strength, both signals must be amplified – that is, the booster must have a forward and a reverse amplifier, usually connected to the same antenna at either end. This concept is illustrated in figure 1.
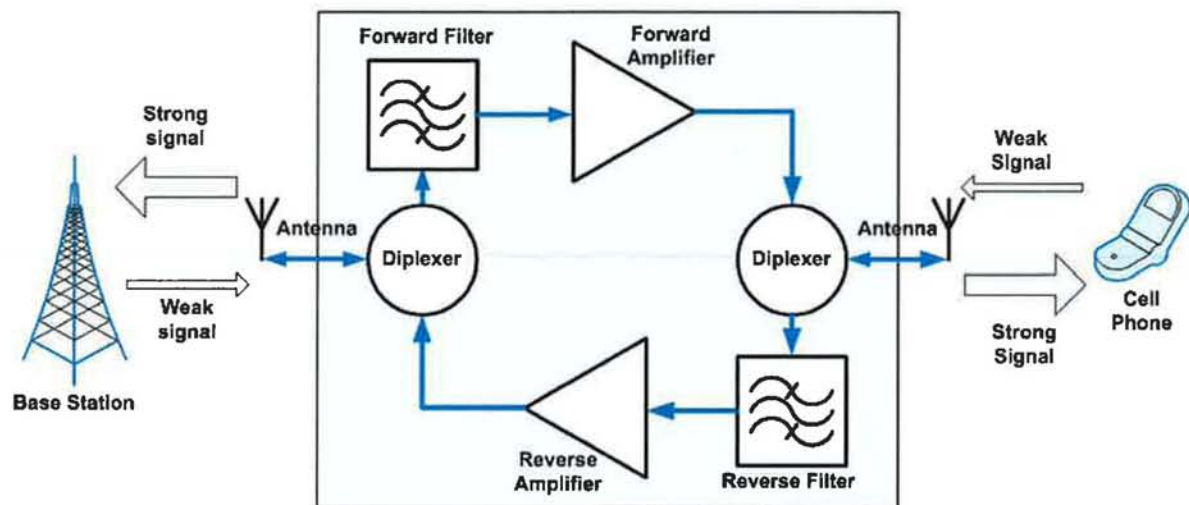

Figure 1: Simplified Block Diagram of a Bidirectional Amplifier

The task of amplifying signals that flow in both directions is facilitated by the fact that cellphones communicate on two widely separated frequencies, one for forward signals and one for reverse signals. Thus the forward filter passes only signals at forward frequencies, and the reverse filter passes only signals at reverse frequencies. The diplexer also aids in

separating the forward and reverse signals, and some types of diplexer actually incorporate the filters.

Fixed amplifiers may use a directional antenna directed toward the nearest base station, since neither the amplifier nor base station move. Pointing a directional antenna at the nearest base station improves signal strength and reduces interference from other base stations.
For mobile stations, the antenna is always Omni-Directional.

Additional electronics may be incorporated to provide for the two frequency bands used by cellphones (commonly 800MHz and 1900MHz)[1], to control the transmitted power (Automatic Gain Control), and to detect and prevent oscillation (feedback from the outside antenna (favoring the base station) and the inside antenna (for the cell phone).
Wilson Electronics (among several others) manufactures a variety of amplifiers, for fixed in-building and mobile in-vehicle use. All of Wilson's products are bi-directional.

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[1] The FCC designates the 800MHz band as "Cellular" and the 1900MHz band as "PCS", for Personal Communication Systems. However, both are served by the same cellphone and network infrastructure in almost all cases.

2.1 Forward-Link-Only Cellphone Amplifier

It's instructive to examine the case of a unidirectional cellphone amplifier that only amplifies forward link signals.
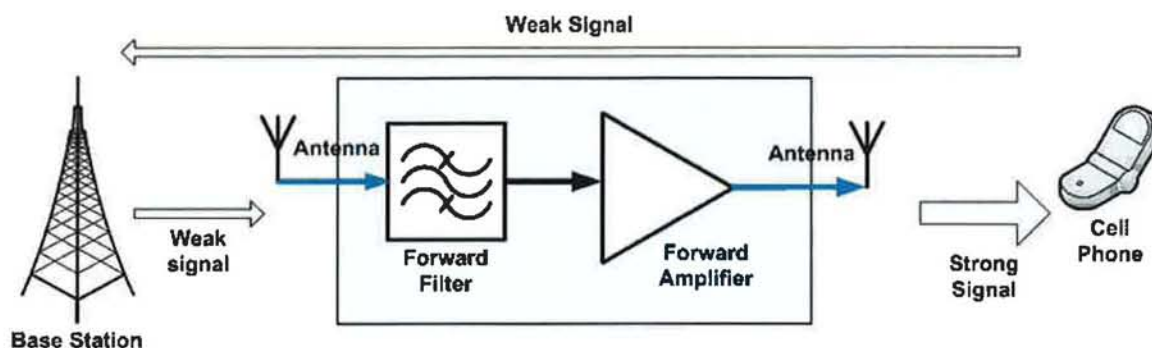

Figure 2: Unidirectional Cellular Amplifier

Figure 2 shows a simplified block diagram of a unidirectional, forward link amplifier. As can be seen, the "signal boost" benefit is present only in the forward direction, so such a device will indeed provide "more bars" on the cellphone display, because the bars reflect only the received, forward signal strength. In the reverse link, a weak signal will remain weak; hence it is doubtful that any significant range extension can be realized. This is in contrast to Figure 1, which shows signal boost in both directions and therefore does extend range.

2.2 Cellular Standards

The current set of cellphone standards is legion. However, they break down into two "tracks": the GSM track and the CDMA track. The international bodies that regulate the technical specifications are designated 3Gpp (Third Generation Partnership Project) for the GSM track and 3Gpp2 for the CDMA track. The evolution along each track is shown in figure 3[2].

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[2] Obsolete standards TDMA (US) and PDC (Japan) are omitted from this chart for clarity. Both are being phased out worldwide as 3G is phased in. Several of the standards shown also come in different "flavors", e.g. HSPA (High Speed Packet Access) may be only in the forward or down link (HSDPA) or the reverse or up link (HSUPA).
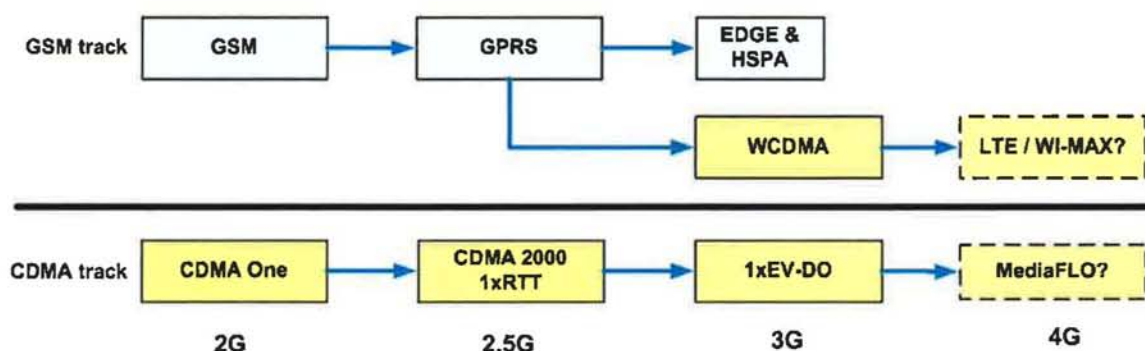
Figure 3: Evolution of Cellular Standards

The blocks with solid outlines in Figure 3 are standards used in cellphones today, and they will continue to be used for the foreseeable future.

The CDMA protocols shown in yellow all use a similar technique for initiating a call. The technique includes a protocol called Open Loop Power Control, and it is this protocol that can be disturbed by a unidirectional signal booster amplifier.

The evolution to 4G (dashed outlines) is not yet clear, but it is probable that it will also use open loop power control.

2.3   Open vs. Closed Loop Power Control

In **open loop** power control, the cellphone alone makes all decisions relating to its transmitted power. The cellphone adjusts its transmitted power by monitoring the received power of a "pilot" channel transmitted by the base station. The cellphone then transmits a power that is in inverse proportion to the received pilot power. For example, if the pilot power received from the base station doubles then the transmitted power from the cellphone is halved.

In **closed loop** power control the base station makes all the decisions related to cellphone transmitted power. The base station transmits "feedback" control signals that tell the cellphone to increase or decrease its forward link transmitted power by a preset increment in response respectively to a decrease or increase of reverse link power and/or quality received from the cellphone.

Most systems have two closed loops; the first or "outer" loop endeavors to maintain received power at the correct level; the second or "inner" loop monitors the frame error rate and corrects the outer-loop power control to achieve the target error rate.

After access has been successfully established and the system is exchanging information, all standards use hybrid open/closed-loop power control in which both cellphone and base station make joint decisions on the cellphone's transmitted power. Open loop provides a "coarse" adjustment while the closed loops provide "fine" adjustment. When all three loops are engaged, the open loop setting will be continuously in error with the amplifier on. Only the closed loops will be available to correct the error.

2.4 Forward-Link-Only Amplifier Prevents CDMA Call Initiation

In CDMA systems large groups of cellphones use the same frequency at the same time in the same cell as well as in adjacent cells. Thus, because the base station reverse link receiver can hear all transmissions simultaneously, it is important not to initiate a call using excessive transmission power. (It would be like shouting in a quiet room.)

When a cellphone needs to establish a link with a base station, it transmits a special signal called an Access Probe (Access Preamble in WCDMA) which alerts the base station that it is requesting a link. The initial transmitted power of this probe is determined by the power received from the base station. If the mobile receives no acknowledgement of the probe from the base station, it sends another probe at an incrementally higher power.

This process is continued a specified number of times until the cellphone receives an acknowledgement; if no acknowledgement is received during the last specified time, the call attempt is dropped.
The network presets the size of the increment (step) and the maximum number of steps allowed. A typical probe sequence is illustrated in Figure 4.
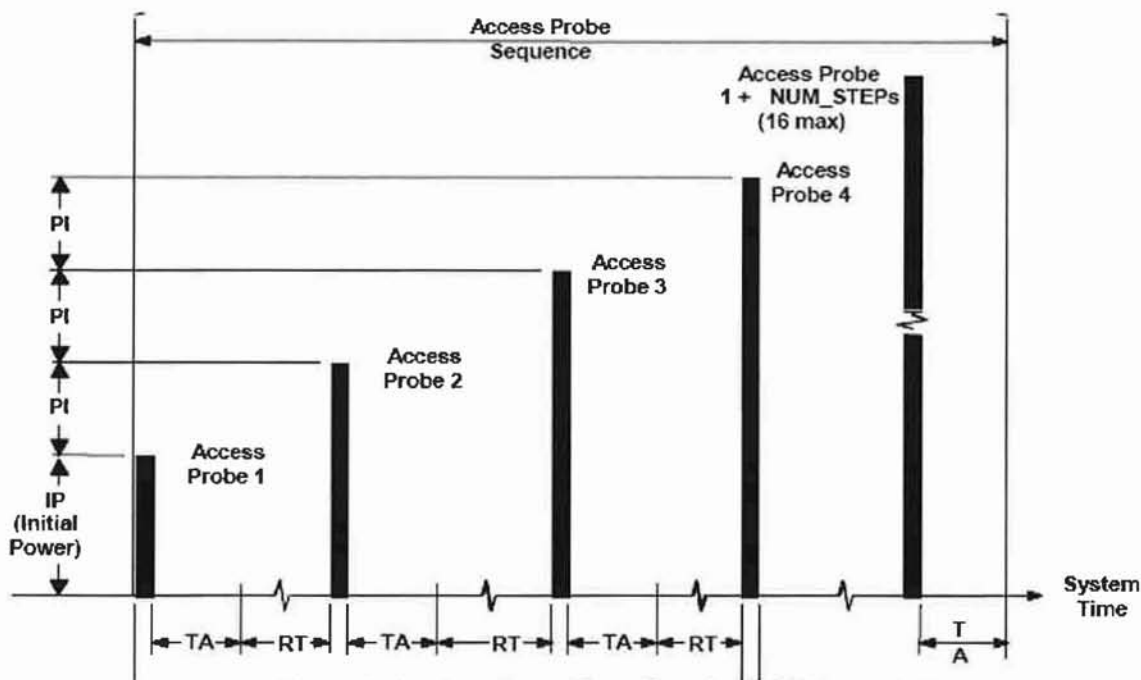

Figure 4: Random Access Procedure for CDMA One & 2000

Source: Footnote 3, Figure 2-10. Access Attempt (Part 2)
See also: Footnote 4, Figure 8.3.5.3-2. Access Probe Sequences

This sequence is used in the reverse link whether the call is incoming (cellphone terminated) or outgoing (cellphone initiated.)

Table 1 and its footnotes provide references to the appropriate sections of the standard documents (listed in the footnotes) for each of the CDMA protocols.

Protocol	Power Control Mode	
	During call setup	After call setup
CDMA One CDMA 2000 1xRTT 1xEV-DO	Open loop[3]	Open and Closed Loop[4]
WCDMA	Open Loop[5]	Open and Closed Loop[6]

Table 1: Power Control Modes for CDMA Protocols

2.5 Forward-Link-Only Amplifier Continues to Cause Power Control Errors Once Call is Established

If the cellphone succeeds in making its call regardless of the effects of the amplifier, its problems are not over.

The closed loops are intended to provide "fine" power correction of the open loop estimate. Typically these loops increment power in 0.5dB steps. But with, say, 30dB of open loop error, it would need 60 outer-loop power control cycles – lasting over a second – to bring the cellphone reverse link power up to its correct level. While this is going on the reverse link power is too low for the inner loop to perform any signal quality measurements.

Once the correct power is established the system may work, but in the (frequent) case of handoff – hard handoff (change frequency), soft handoff (connect with another base station), or softer handoff (connect with another sector in the same base station) the entire correction sequence would have to begin again.

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[3] 3GPP2 C.S0003-A-1 clause 2.2.1.1.2.1.5, Access Channel Procedures

[4] 3GPP2 C.S0002-A-1 clause 2.1.2.3.2, Closed Loop Output Power

[5] 3G TS 25.214 V3.1.1 (1999)- ETSI TS 125 214 V3.1.1 (2000-01) chapter 6, Random Access Procedure

[6] 3G TS 25.214 version 3.1.1 Release 1999 Clause 5.1.2.2 Ordinary transmit power control

Figure 5 shows an example of how the closed loops will be performing outside their designed parameters due to the presence of the forward link amplifier.
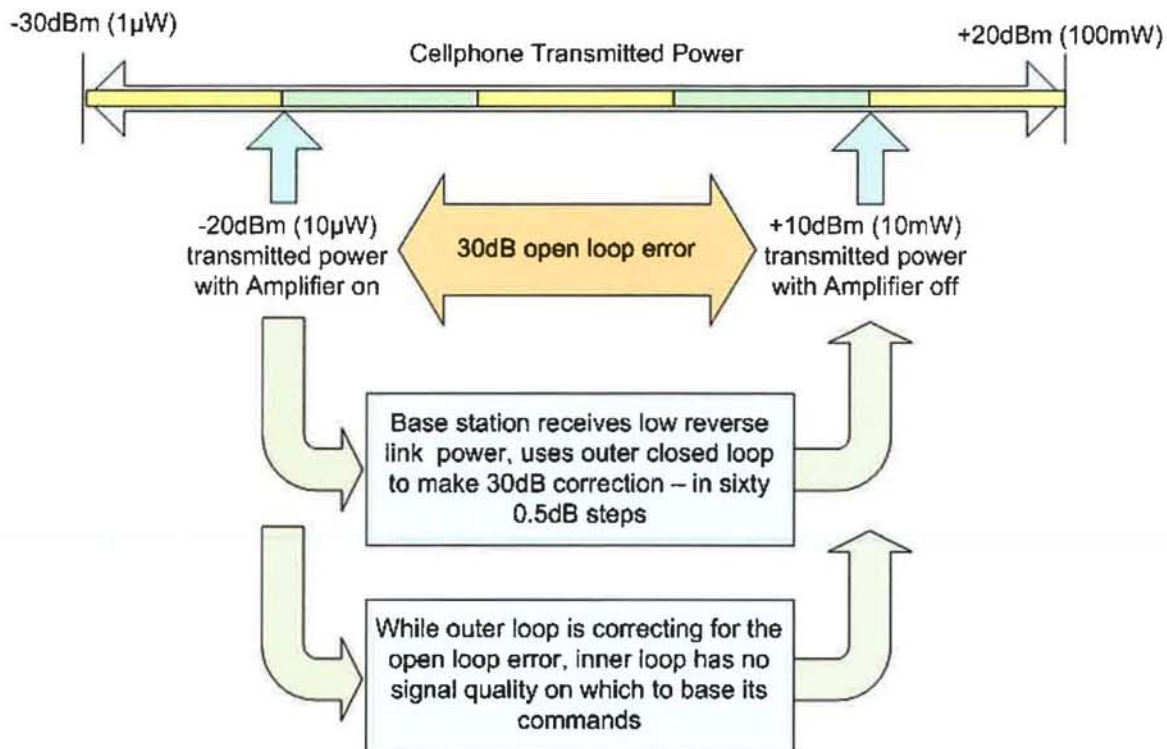

-30dBm (1µW)   Cellphone Transmitted Power   +20dBm (100mW)

-20dBm (10µW) transmitted power with Amplifier on   30dB open loop error   +10dBm (10mW) transmitted power with Amplifier off

Base station receives low reverse link power, uses outer closed loop to make 30dB correction – in sixty 0.5dB steps

While outer loop is correcting for the open loop error, inner loop has no signal quality on which to base its commands

Figure 5: Unidirectional Forward link amplifier keeps the closed loops busy during a call

GSM, GPRS, EDGE, and HSPA also use open and closed loop power control[7]. Open loop is used alone at the beginning of a packet transmission. As a result there may be a noticeable effect on calls with these protocols when a forward link amplifier is used.

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[7] cf. for GSM: 3GPP TS 45.008-7b0, Radio subsystem link control, Chapter 4, RF Power Control, and Annex B: Power Control Procedures; and for GPRS: 3Gpp TS43064-6a0, Overall description of the GPRS radio interface, clause 6.5.8, Power Control Procedure.

3. Conclusions

Section 2 of this report demonstrates the technical basis for requiring reasonable gain balance in cell phone booster amplifiers in order to insure reliable communications, especially under marginal (weak signal) conditions.

Without mandatory gain balance requirements, the public's interests are compromised. Booster amplifiers with insufficient gain balance actually worsen communications when needed most, i.e. when communications without a booster amplifier are unreliable if at all possible. This can be especially critical in emergency situations.

4. Recommendations

Cell phone booster amplifiers should be required to have active gain in both the forward link and the reverse link directions. Such gains should be nominally equal. Any gain imbalance should be required to be within the limits allowed by relevant cellular standards.

5. Acknowledgement

The background material presented in section 2 is largely from: *The Effects of a Forward-Link-Only Amplifier on the Operation of a CDMA Network*, by Ray W. Nettleton, PhD, June 2008. This paper is available from Wilson Electronics.